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THE WHEAT STEM AND LEAF RUST EPIDEMICS OF 1938 IN KANSAS [1]

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The 1938 Kansas wheat crop was officially estimated at 193,000,000 bushels as late as June 10, but was finally reported at 152,114,000 bushels. Many opinions have been expressed as to the causes of the rapid decline of the crop. The many complicating conditions involved during the crop season make it difficult to evaluate the significant factors responsible for the rapid deterioration of the crop.

The impression exists that losses from stem rust are uncommon and of little consequence in the winter wheat belt of the Great Plains area. The stem-rust epidemic of 1935 in Kansas was accepted as something unusual and not likely to occur again for years because the only other major general epidemic up to that time occurred in 1904. Yet, Kansas and the hard winter wheat belt were visited again by stem rust in 1937 and 1938. Strangely enough, all three of these rust years occurred while Kansas was still struggling with the drouth. It has been suggested by some investigators that the cause of the 1935 epidemic was the culmination of a set of unusual conditions, all perfectly timed, and that such a combination rarely occurs. [3]

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[1] Contribution No. 394 from the Department of Botany, Kansas Agricultural Experiment Station, in cooperation with the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture

[2] The authors gratefully acknowledge the help of John O. Miller, Extension Specialist in Plant Pathology, Kansas State College, who gave aid in connection with field surveys.

[3] E. C. Stakman. The black stem rust epidemic in 1935. Pub. by Miller's National Federation, Aug. 16, 1935.

It now seems evident that environmental and other conditions are favorable rather frequently and that stem-rust losses are a matter that must be reckoned with in Kansas. It is, however, plainly evident, that the 1938 Kansas wheat crop was threatened with one of the worst epidemics of stem rust in the history of the State.

Crop Conditions Leading up to the Stem-rust Epidemic of 1938

The winter wheat crop of Kansas developed under environmental conditions during the fall and early spring which indicated that one of two things would probably happen. If ample moisture did not come during the heading stage, the lack of subsoil moisture would cause the crop to "burn up," and if moisture came in sufficient amounts, or more than adequate amounts, the possibility of rust loss would be great. Drouth conditions continued to prevail in most of the wheat areas of Kansas up to February, and the best informed individuals were not optimistic over crop prospects. As it turned out, Kansas probably obtained the largest yield possible under the conditions of above normal rainfall that occurred. Throughout the winter and early spring the crop looked "good from the top," but the absence of subsoil moisture was decidedly limiting the crop prospects.

In much of Kansas where wheat was sown in the fall of 1937 there was moisture for germination, a good stand was obtained and the fields generally went into winter in a satisfactory condition. The winter was mild and the crop survival was excellent. The extremely mild weather of February and March stimulated early top growth and the crop was several weeks advanced when the freezes of April 2 and 8 occurred in the Great Plains area. Speculation was rife on the damage from low temperature, and great alarm was spread as to its importance. While the freeze unquestionably did damage and all its injury may not have been accounted for, it is believed that the importance of freezing injury was greatly overestimated.

The cold snap was followed by excessive rainfall during May and June. Cool nights and heavy, early infection of leaf rust delayed the crop. Heading was slow and uneven, and, in some fields, never completed. In south-central Kansas, the straw was especially rank, weak, and soft. In most fields lodging was severe because of buckling and subsequent breaking of the straw at the uppermost nodes. The wheat plants in that area died prematurely, producing immature straw and shriveled grain. Many fields in this condition were examined and in most cases they presented an ashy, scalded appearance instead of the normal golden yellow. This unnatural color or ripening was plainly noticeable from the road. A few days later all

plants in these fields were dead. An examination of the roots and crowns of wheat plants and the water-soaked condition of the soil indicated that much of the injury was somehow related to environmental conditions affecting the plants.

Although no attempt will be made here to list all the important factors concerned with the decline of the 1938 wheat crop, it is certain that those listed in chronological order below were important ones:

1. A lack of fall and winter soil moisture in western half of Kansas, which led to inadequate and shallow root development.

2. Unusually mild weather in early spring initiated excessive top growth, so that the crop was several weeks in advance of its normal development at the time of the freezes of April 2 and 8.

3. Very early and abundant leaf-rust infection appeared in April and increased with devastating force throughout the growing season.

4. Heavy rainfall in May and June produced a water-logged soil over wide areas in Kansas. Combined with an advanced stage of sappy growth, the unfavorable soil conditions stimulated crown and root rots and weak straw, which later became brittle. In certain counties large losses occurred from floods and hail.

5. Stem-rust infection appeared in southern Kansas a month earlier than normally. While stem rust did considerable damage in some counties, it caused less loss than in 1935. Central and eastern Kansas would have experienced larger losses had it not been for the premature dying of vast areas of Early Blackhull and Blackhull, the cool night temperatures, and the large areas of Kawvale and other semiresistant varieties in eastern Kansas. Stem rust in 1938 never had an opportunity to exert its full influence.

6. The presence of other diseases such as black chaff, glume blotch, and foot-rots unquestionably were contributing factors. Towards the end of the season it was observed that

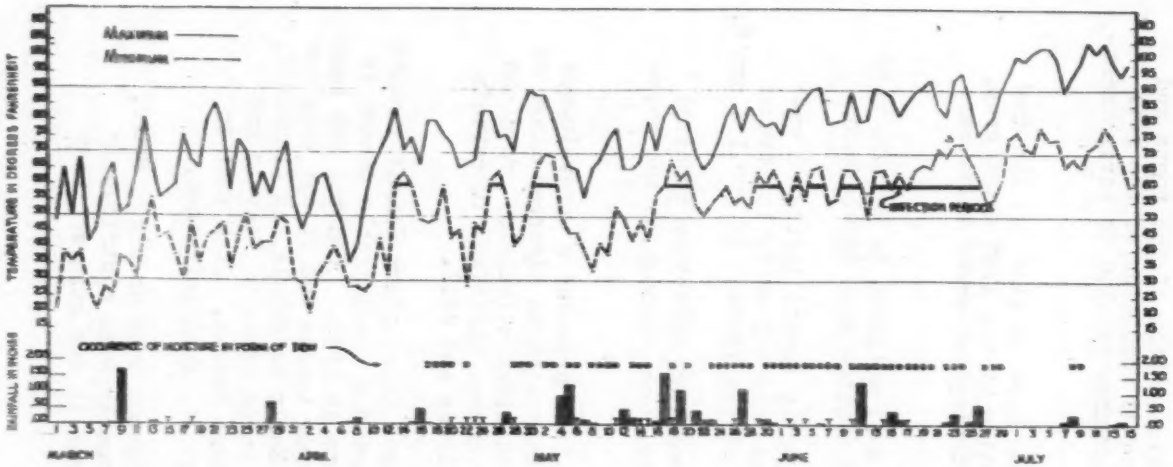

FIGURE 1a: MAXIMUM AND MINIMUM AIR TEMPERATURES, RAINFALL AND DEW OCCURENCE, AND PERIODS FAVORABLE TO THE DEVELOPMENT OF STEM RUST AT MANHATTAN, KANSAS, FROM MARCH 1 TO JULY 15, 1938.

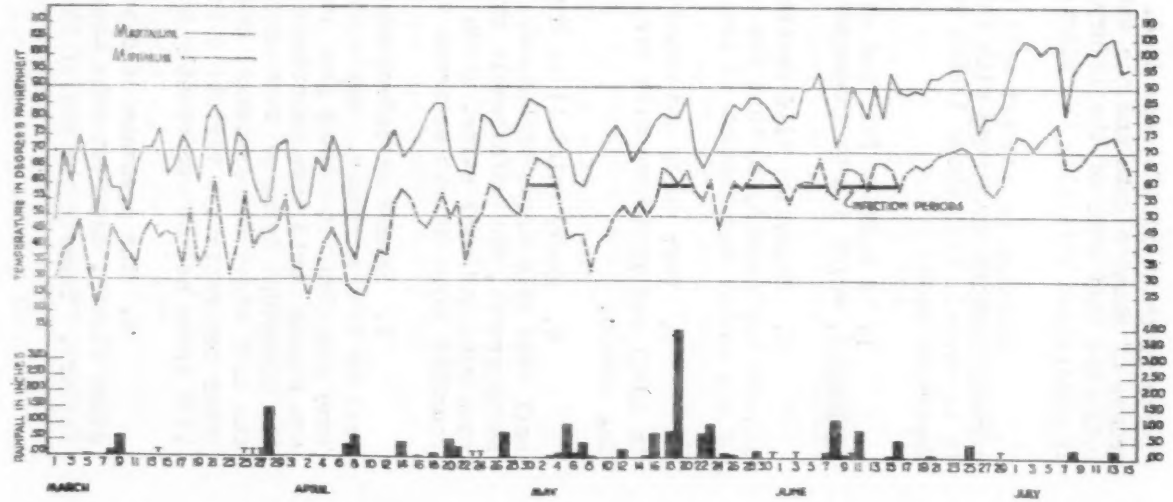

FIGURE 1b: MAXIMUM AND MINIMUM AIR TEMPERATURE, RAINFALL, AND PERIODS FAVORABLE TO THE DEVELOPMENT OF STEM RUST AT WELLINGTON, KANSAS FROM MARCH 1 TO JULY 15, 1938

Septoria nodorum Berk. was present on the shrunken, discolored, and broken nodes of the wheat, a common and widespread sign and symptom of the maturing crop. 4/ The importance of this organism in the decline of the crop is a matter worthy of further study, since this fungus has been reported in literature as a serious parasite. It is believed, however, that the excessive moisture in May and June markedly favored the incidence and importance of the above-mentioned diseases.

With this information in mind, it is evident that it would be impossible to evaluate the importance of each factor, or to estimate the loss that each disease may have caused. The chief purpose of this paper is to give a general picture of the wheat rust situation and to point out those facts about the wheat crop in as far as they were observed by the writers.

The Northward Spread of Stem Rust

As in 1935 and 1937, the northward movement of stem rust was again evident in 1938. Records show the inception of stem rust in southern Texas and its steady advance northward through Oklahoma, Kansas, and Nebraska. It was first reported from southern Texas (San Antonio) on March 27, from central Texas (Waco and Temple) on April 13, and from northern Texas (Denton) on April 23. About this time it also was reported present in plots examined at College Station, and on May 1, at Chillicothe, Texas. Beginning on May 4, a strong wind blew continuously from the south for several days at an average velocity of 20 miles per hour. 5/ This was followed by another period of strong winds for 3 days and nights about May 9. Stem rust was reported at the end of April in southern Oklahoma. 6/ On May 7, Chester reported

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4/ Creager, D. B. Septoria nodorum on nodes of wheat in Kansas. Plant Dis.Rep. 22: 241-242. 1938.

5/ Plant Disease Reporter 22: 157. 1938.

6/ Plant Disease Reporter Supplement 112,page 6. 1939.

FIGURE 1: MAXIMUM AND MINIMUM AIR TEMPERATURE, RAINFALL, AND PERIODS FAVORABLE TO THE DEVELOPMENT OF STEM RUST AT WELLINGTON, KANSAS FROM MARCH 1 TO JULY 15, 1938

TABLE 1: AVERAGE RAINFALL AND NUMBER OF RAINY DAYS IN SECTIONS OF KANSAS FOR APRIL, MAY, JUNE, AND JULY, 1935, 1937, 1938.

MONTH	SECTION OF STATE	RAINFALL IN INCHES						NUMBER OF RAINY DAYS		
		AVERAGE			DEPARTURE					
		1935	1937	1938	1935	1937	1938	1935	1937	1938
APRIL	EASTERN	2.13	2.04	2.32	-1.14	-1.18	-0.98	8	7	7
	CENTRAL	1.02	0.57	2.56	-1.45	-1.90	+0.15	5	3	8
	WESTERN	0.25	0.39	2.38	-1.78	-1.59	+0.38	2	3	8
	STATE	1.13	1.00	2.41	-1.46	-1.53	-0.12	5	4	8
MAY	EASTERN	10.22	4.06	9.75	+5.37	-0.77	+4.82	17	11	15
	CENTRAL	8.46	3.96	8.26	+4.64	+0.12	+4.33	15	11	15
	WESTERN	4.65	1.44	4.66	+2.00	-1.24	+1.94	13	8	10
	STATE	7.78	3.55	7.56	+4.01	-0.63	+3.70	15	10	12
JUNE	EASTERN	7.30	3.59	5.43	+2.40	-1.22	+0.61	15	7	10
	CENTRAL	5.05	3.18	4.39	+0.91	-0.88	+0.32	12	8	8
	WESTERN	2.90	3.03	2.41	-0.05	+0.11	-0.50	8	8	8
	STATE	5.08	3.27	4.08	+1.08	-0.71	+0.10	12	8	9
JULY	EASTERN	0.47	3.97	3.58	-3.30	+0.26	-0.13	2	9	6
	CENTRAL	0.76	3.76	2.71	-2.34	+0.69	-0.35	2	8	7
	WESTERN	0.80	1.70	2.42	-2.05	-1.09	-0.36	3	6	8
	STATE	0.68	3.14	2.90	-2.56	-0.06	-0.29	2	8	7

TABLE 2: MEAN TEMPERATURES FOR KANSAS DURING APRIL, MAY, JUNE, AND JULY, 1935, 1937, 1938

MONTH	SECTION OF STATE	MEAN TEMPERATURE IN DEGREES FAHRENHEIT					
		AVERAGE			DEPARTURE		
		1935	1937	1938	1935	1937	1938
APRIL	EASTERN	52.8	54.8	56.6	-3.0	-0.9	+0.9
	CENTRAL	52.6	55.0	55.2	-2.7	-0.3	-0.1
	WESTERN	51.4	53.2	55.0	-1.4	+0.4	+0.1
MAY	EASTERN	60.4	66.8	64.6	-4.1	+2.1	-0.1
	CENTRAL	60.0	67.3	63.5	-4.1	+3.0	-0.8
	WESTERN	56.7	65.9	63.5	-5.4	+3.7	-0.3
JUNE	EASTERN	70.6	75.2	73.7	-3.6	+0.9	-0.5
	CENTRAL	71.1	75.1	74.2	-3.2	+0.7	-0.2
	WESTERN	71.2	72.5	73.8	-1.2	0.0	0.0
JULY	EASTERN	84.4	80.7	80.7	+5.6	+1.7	+1.6
	CENTRAL	84.8	82.6	81.8	+5.1	+2.7	+1.8
	WESTERN	83.6	81.7	80.9	+5.6	+3.6	+1.8

stem rust around El Reno, Chickasha, Anadarko and Lawton, but, according to W. M. Osborn, rust had been seen at Lawton 10 days prior to this date.

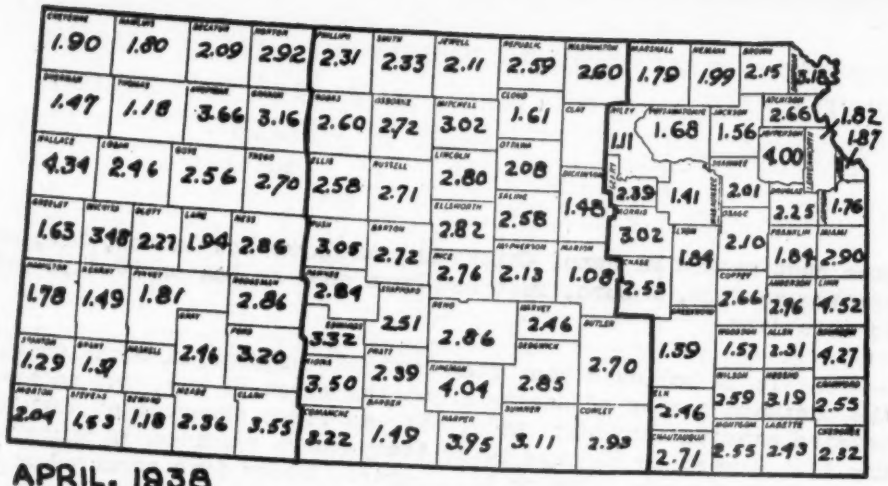
It is believed that stem rust was present in counties along the southern border of Kansas about the first of May, but no extensive examinations were made. It was first observed at Manhattan May 11. A week or 10 days later traces were reported in numerous counties in Kansas. During this period, heavy dews occurred and moisture conditions were favorable, but night temperatures were too low for infection. Figures 1a and 1b show that brief periods favorable for infection occurred at Manhattan on April 13-15 and 25-27, while in southern Kansas (Wellington) these periods seem lacking. From April 30 to May 3 and from May 16 to 21 brief periods favorable for infection occurred at Manhattan and Wellington, Kans. From the middle of May to June 1, stem rust became widely distributed in small amounts in central and eastern Kansas. At this time the crop was not more than a few days if at all earlier than normal.

The wheat crop had not suffered seriously from lack of moisture up to the time of the April freeze, despite the fact that subsoil moisture was lacking. This is in contrast with the situation prevalent in 1935 and 1937 during a comparable stage of crop development. The wheat in western Kansas was in much better condition than in 1935 and 1937.

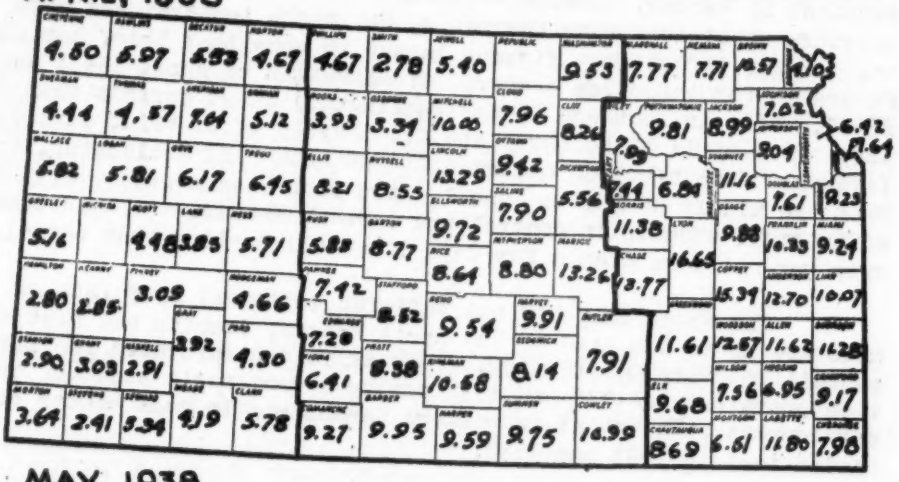
Meteorologic Conditions in Kansas in 1938 as Affecting Stem Rust

Weather conditions during May and June in general were somewhat similar to those of 1935 and 1937, yet certain features were distinctly different. Table 1 shows the rainfall for eastern, central, and western Kansas for April, May, June and July and the number of rainy days for the three stem-rust years.

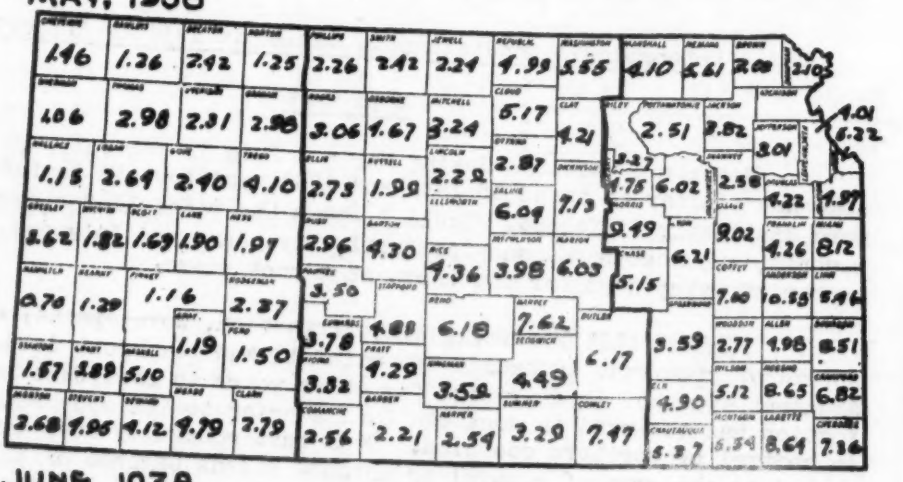
Factors that generally limit infection, development, and spread of stem rust in Kansas are rainfall and recurrent dews. Abundant evidence is on record for other years to show that infection has occurred in southern Kansas prior to its appearance in central or northern counties. Stem rust generally does not spread to the crop of central or nothern Kansas because of lack of rainfall in May and early June. This situation is usually



APRIL, 1938



MAY, 1938



JUNE, 1938

FIGURE 2 : TOTAL PRECIPITATION RECORD FOR KANSAS, APRIL, MAY, AND JUNE, 1938

accompanied by warm, dry winds and a rapidly maturing wheat crop, which make conditions unfavorable for further stem-rust spread. The rainfall totals for April, May, and June, 1935 and 1938, for eastern, central and western Kansas, and the State as a whole were nearly the same, but much more than for 1937. Table 1 shows that the precipitation for 1938 was well distributed over the two-month (May-June) period. Figure 2 shows the precipitation by counties for the various sections of Kansas for April, May and June, 1938. Added to this were the frequent dews that occurred in 1938, which generally are not nearly so prevalent in Kansas. It was important to chart the rainfall for nothern as well as for southern Kansas. Figures 1a and 1b show how similar the precipitation amounts and periods were, indicating that moisture fell over wide areas of central Kansas and on the same dates. The principal difference was that the amounts that fell on specific dates were considerably greater in the southern part of the State. There were slightly fewer rainy days during 1938 than in 1935, except in April and July when more were reported (table 1).

Figure 3 shows the maximum and minimum daily temperatures from May 15 to June 24 for 1935, 1937, and 1938. Similarities will be noticed in the trend of temperatures during each of the three years, yet there are some points of difference. The period from the middle of May to about the middle of June is regarded as very important in the development of the Kansas wheat crop and stem rust.

Table 2 shows the mean temperatures for eastern, central, and western Kansas and the departures for 1935, 1937, and 1938. If these were used as a criterion, it would seem that 1938 mean temperatures for May and June were nearer the normal than those for the same months in 1935. While mean temperatures doubtless are important, studies have shown that the minimum and maximum temperatures are more important. As mentioned in a former report, not until minimum temperatures become high enough to favor abundant germination of urediospores are heavy stem-rust infections noted in Kansas. 1/ The minimum temperatures for germination seem to lie

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1/ Plant Disease Reporter Supplement 107, Aug. 1, 1938.

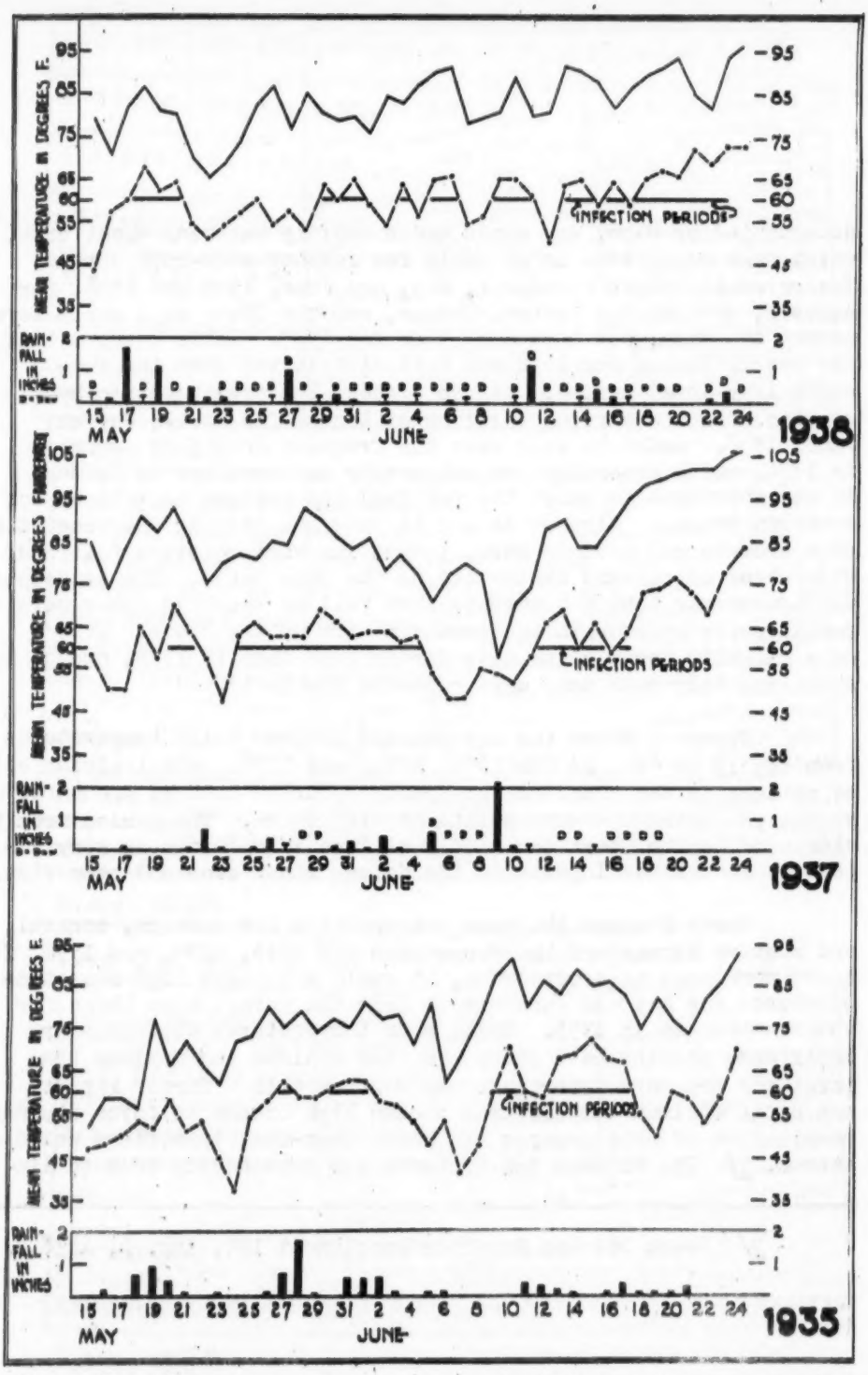


FIGURE 3: MAXIMUM AND MINIMUM AIR TEMPERATURES, RAINFALL AND PERIODS FAVORABLE FOR THE DEVELOPMENT OF STEM RUST AT MANHATTAN, KANSAS, FROM MAY 15 TO JULY 24, 1935, 1937, AND 1938

between 55-60° F. If we accept 60° F. as the minimum favorable temperature at which abundant germination and infection occur, then the minimum temperature curve for 1938 shows that several infection periods took place in northeastern (Manhattan) Kansas, and southern (Wellington) Kansas, as indicated in figures 1a and 1b.

The meteorologic conditions which were most favorable for infection and spread appeared to be confined largely to a period from May 15 to June 20. This same condition prevailed in 1935 and 1937. In each of these years short breaks occurred when for a few days conditions were less favorable for the spread of stem rust, but figures 1 and 3 indicate that May 15 to June 20 was the critical period.

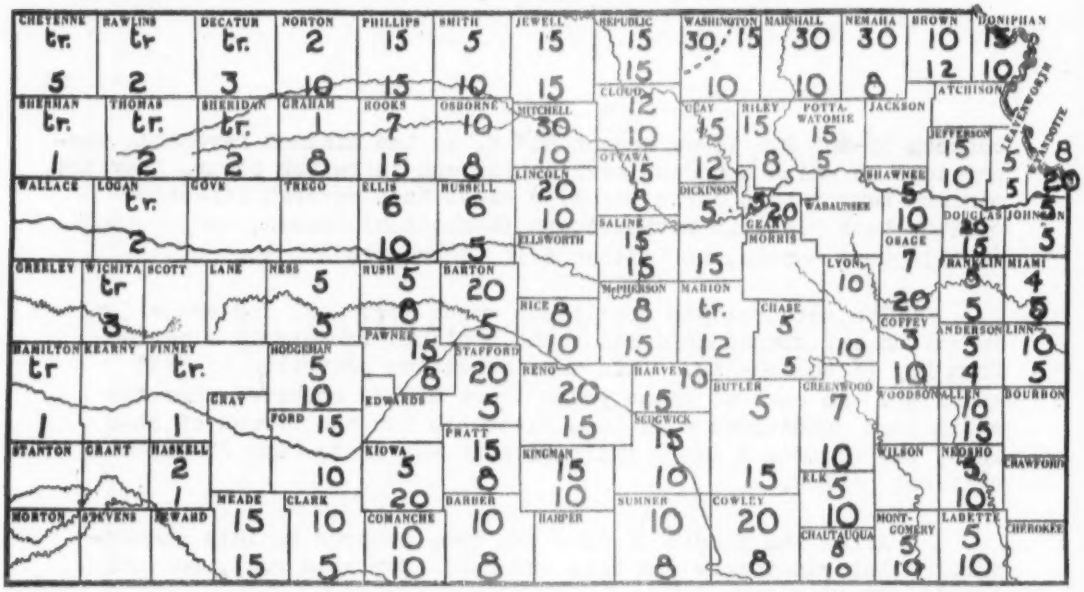
After the middle of June the crop matures rapidly and environmental conditions are less favorable for stem rust, so that little spread occurs.

Moisture was definitely not the limiting factor in 1938. A comparison of the favorable "infection periods" during 1935, 1937, and 1938 at Manhattan is presented in figure 3. This comparison is on the basis of 60° F. being the minimum temperature favorable for infection and spread of stem rust. If 55° F. were used as the lowest favorable temperature, figure 3 would present a still more contrasting picture. The temperature curves indicate that periods favorable for infection in 1938 were short and were separated by unfavorable periods, while in 1935 and 1937 there were prolonged favorable infection periods. It is believed by the writers that this largely accounts for the fact that stem rust was so unusually slow in establishment, increase, and dissemination in the 1938 Kansas crop.

This belief is supported by the following facts concerning the period from the middle of May to the first week in June: In 1935 there were 6 days and nights favorable for infection; in 1937 there were 15 such days and nights; while in 1938, there were only 5. It should also be noted (fig. 3), that in 1938 the favorable infection periods were short and discontinuous as compared with the more prolonged periods in 1935 and 1937.

Stem rust was observed at Manhattan on May 11, almost a month earlier than usual. Although found in fields in central and eastern Kansas and as far north as Riley county on June 4, it was present only in small amounts. Stem-rust infection in 1937 made its appearance first in the southern counties from Harper eastward and the trend of heaviest infection was in a northeasterly direction. It

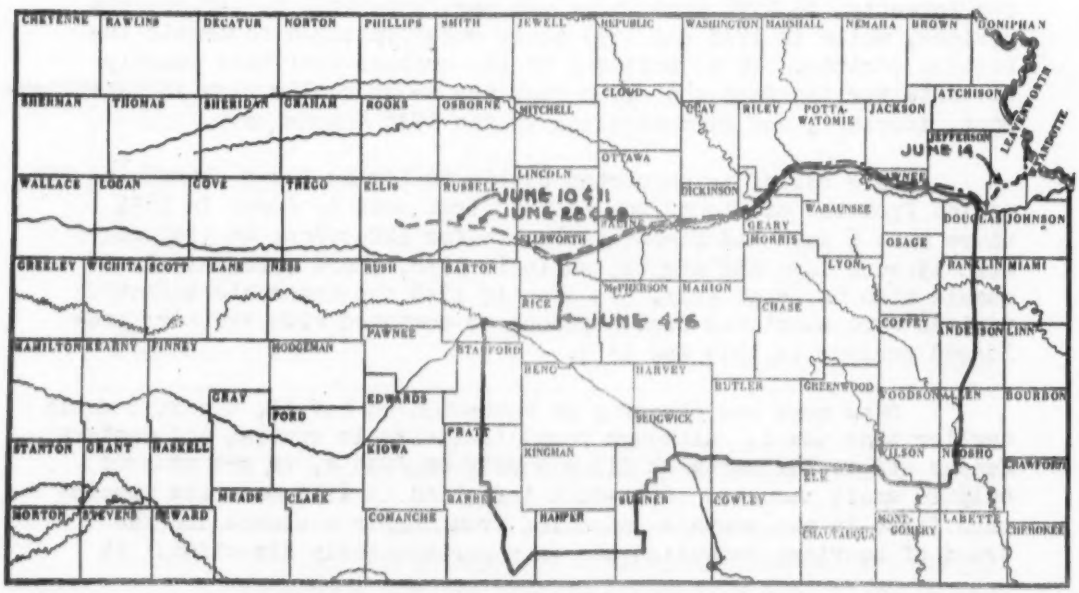
WHEAT STEM & LEAF RUST - 1938



KEY—
UPPER FIGURE IS PERCENTAGE LOSS FROM STEM RUST: AVERAGE 9.3%.
LOWER FIGURE IS PERCENTAGE LOSS FROM LEAF RUST: AVERAGE 8.1%.

ESTIMATES BY COUNTY AGENTS, FARMERS AND MILLERS

FIGURE 4:



AREAS INSPECTED FOR WHEAT STEM RUST IN 1938. DATES ON WHICH TRIPS WERE MADE ARE INDICATED.

FIGURE 5

was noted in 1938, however, that infection centered largely in the south central counties of Barber, Harper, and Sumner, whence it spread fan-wise, northward, with lighter infections in southeastern Kansas. Traces were present in central Kansas on June 4 on from 25 to 50 percent of the culms. The crop at that time was from 14 to 18 days from harvest. In the southern counties of central Kansas, some fields had from 5 to 10 percent rust on most of the culms, but the crop, 7 to 10 days from harvest, was rapidly deteriorating from other causes already mentioned. Damage from rust was, therefore, relatively unimportant except in occasional fields. Leaf rust had taken its toll and the water-logged soils and foot-rots were contributing their share of the injury. As one proceeded northward, it was evident that much more of the crop would "slump" in a manner similar to that occurring in Barber, Harper, Kingman, and Sedgwick counties. When questioned about the deterioration of the wheat crop, farmers almost invariably said: "too much rain;" "no good wheat crop ever was raised in Kansas in a wet year like this one." Some felt the freeze was largely responsible, but most people who gave weight to this theory at first had to revise their ideas later in the season. Because of unfamiliarity with the complicating factors and familiarity with the stem-rust damage in 1935 and 1937, county agents, millers, and others overestimated the injury attributable to stem rust. Figure 4 shows their estimated percentage loss from stem and leaf rusts. The writers believe the leaf-rust percentages are underestimated, while those for stem rust are too high in most counties. This is not unexpected because "red rust" (Puccinia triticina Erik.), in the minds of most people, is believed to cause little damage, while "black rust" (P. graminis tritici Pers.) always is the cause of injury, even if only a small amount is present.

By June 15 stem rust was present in most fields. Western Kansas escaped with the least injury from both stem and leaf rusts, although the infection and spread of stem rust were much farther west than usual in the counties bordering Oklahoma. For a time it appeared that northwestern and all of northern Kansas might have a severe loss because of later ripening of the crop. However, owing to hot weather, the rust failed to develop sufficiently to cause much damage.

Central Kansas had a moderate amount of damage, but just about the time that stem rust was appearing in large amounts the fading wheat crop checked any large loss that would have occurred.

In Ellis and Russell counties, and in counties north of these, many fields were severely attacked and considerable damage occurred.

The loss was heavy in the soft wheats of eastern Kansas, especially in the eastern tier of counties where varieties other than Kawvale were grown. The most impressive feature of the wheat crop after the middle of June was the rapidity of maturity brought about by numerous factors. Crop deterioration, followed by the rapid rise of temperature the last of June, brought stem-rust damage to a standstill and prevented the disease from reaching its maximum intensity.

Figure 3 shows that rain, trace of rain, or dew occurred each day, except two, during the period May 15 to June 24, 1938, at Manhattan. This is much more striking than in either 1935 or 1937, again demonstrating that moisture conditions were not the limiting factor in 1938.

A comparison of figures 1a and 1b reveals that the periods favorable for infection in southern Kansas did not occur so early or persist so long as they did at Manhattan. This may also help to explain why stem rust did not get under way earlier and why it failed to reach extreme severity in 1938.

Although the mean temperatures for eastern, central and western Kansas in May and June, 1935, were slightly lower than those for 1938, indicating more favorable conditions in 1938, the deciding factor unquestionably was the minimum temperatures for May and June.

Figure 5 shows the counties that were visited and the route followed in the stem-rust survey. Scores of fields were examined and observations were made on the prevalence and severity of rusts as well as crop conditions.

Losses from Stem Rust

Reduction in Yield.--As already stated, it is impossible to estimate the loss from stem rust in 1938, because of the numerous factors which entered into the picture. It is believed, however, that 3 percent is a conservative estimate. County agents estimated an average of 9.3 percent, but careful study by the authors indicates this to be too high (fig. 4).

The highest official estimate of the Kansas yield prior to harvest was 193 million bushels, but only 152 million bushels were harvested. Of that amount, only about 100 million bushels were actually millable. About 34 percent of the grain was fed on the farm or sold for feed at a heavy discount or disposed of otherwise. Part of this loss was due to stem rust. Due allowance is made for the excessive loss from leaf rust, other diseases, water-logged soils, hail and flood damage in arriving at the 3 percent loss from stem rust, which represents about 4 2/3 million bushels.

Abandonment. While no reliable figures are available, there was less abandonment from stem rust in 1938 than in 1937. Thousands of acres were a complete loss in 1938, but the damage was from a combination of the various factors, each one contributing its share.

Loss of Seed. As in the foregoing paragraph, no one factor was responsible for the need of new seed by the farmer on a large acreage, but much loss was sustained because satisfactory seed was not obtained, or farmers had to purchase new seed.

Varietal Resistance. The only observations on stem-rust reaction that were made in 1938 were those made in commercial fields and true comparisons were lacking. Generally speaking, Early Blackhull and Blackhull had low percentages of infection in all fields examined, but the area of the State where they were most commonly grown (south central Kansas), is the region where the crop deteriorated from other causes and stem-rust damage was secondary. It is known that these varieties do have a moderate resistance. Tenmarq, Turkey and Kanred were infected more heavily; especially was this true for Tenmarq and Turkey, while Kanred showed somewhat less infection. In a severe epidemic these varieties react similarly to stem rust.

The soft wheats of eastern Kansas were heavily attacked, especially in the northeastern area. Harvest Queen, Fulcaster, and Clarkan were badly rusted in some counties. Kawvale and Iobred had consistently less damage from stem rust than other varieties, and in the case of Kawvale, its striking freedom from heavy leaf-rust infection early in the season again made it stand out above all other varieties in Kansas in 1938. It should be stated also that in eastern Kansas where the soft or semihard varieties are grown, the wheat was practically free of the lodged, buckled, and broken straw condition so common in central Kansas.

Breaking of Straw

The reaction of certain of the standard varieties of hard winter wheat commonly grown in Kansas and Oklahoma to the conditions of the spring of 1938 is worthy of consideration and comment. It was apparent that a difference exists among the varieties of hard and soft winter wheats of Kansas with respect to the degree to which the straw broke and lodged.

Strange as it may seem, the so-called weak-strawed wheats, such as Kanred, did not show the symptoms of severe buckling of the straw and breaking at the nodes that were so commonly observed in Blackhull, Early Blackhull, and even Turkey in south central Kansas and in areas of Oklahoma. Certainly the factors responsible for straw weakness in Kanred, and those producing the weak-strawed condition of Early Blackhull in the spring of 1938 are entirely dissimilar. It may be safely said that stem rust was not the cause of the straw breaking in the many fields examined, although leaf rust and other diseases may have been contributing factors.

The greatest amounts of rainfall for April, May, and June, 1938, in the hard winter wheat area was in south central Kansas where the most severe damage occurred from "down wheat." The rainfall of this area was somewhat less than that of eastern Kansas for the same period (fig. 2), yet one did not find the soft wheat varieties breaking over. These observations are further borne out by a comparative study of varieties at Manhattan.

Leaf Rust of Wheat in Kansas in 1938

The foregoing discussion is the third report on the environmental and crop factors incident to the development of stem rust of wheat in Kansas. This series of reports has been made primarily to throw more light on stem rust in the great midcontinental winter wheat belt and on the factors favoring the development of epidemics. The present report deals primarily with stem rust of wheat, although leaf rust was economically much more important than stem rust in 1938.

Weather and crop conditions in Kansas have seldom been so favorable for the development of a leaf-rust epidemic as they were in 1938. The extremely mild winter throughout the central and southern plains area favored abundant overwintering of the fungus

in central and southern Texas and an unusually early and rapid increase in the amount of inoculum. The absence of low temperatures and the occurrence of plentiful rains in early spring favored early luxuriant top growth in winter wheat. This naturally provided an excellent medium for propagation for leaf rust. The vast expanse of wheat in such a succulent state, combined with frequent rains during May and early June, provided ideal conditions for the development of an epidemic.

As a consequence of the combination of so many favorable factors, leaf rust made an exceptionally early appearance in Kansas and rapidly developed to epidemic proportions. Before the end of the season the entire wheat-growing area of the State was subjected to the heaviest and most destructive epidemic ever recorded.

Leaf rust was first collected at Manhattan on April 13 about one month earlier than usual, although it was abundant in southern counties during the first week in April. By April 20 extremely heavy infections were reported from central Oklahoma, an area that from that time onward produced vast amounts of inoculum for northern distribution. By May 2 leaf rust was prevalent in nearly all fields in southern Kansas and on May 11, the date of the first collection of stem rust in the State, leaf rust was present in nearly all Kansas wheat fields. From that time on the disease quickly developed to epidemic proportions and by June 1, it overshadowed the danger from stem rust.

The meteorological conditions shown in figures 1,2, and 3 as factors favoring the development of stem rust also favored the development of leaf rust. It must be remembered, however, that leaf rust is able to develop over a wider range of temperature than stem rust, especially at temperatures below 60° F. It is clear that the periods favorable for infection during May were not short, as they were for stem rust, but were prolonged. On the basis of its lower temperature limitations, it seems likely that there were few days in May, 1938, during which conditions did not favor leaf rust infection and development.

Despite the severity and wide distribution of leaf rust, it is extremely difficult to make an accurate estimate on the loss caused by that disease in 1938, owing to the number and importance of other factors affecting yield. After many observations on the wheat crop in various parts of Kansas and a careful

consideration of the opinions of other informed observers, the writers have estimated an average loss of 12 percent for the State. This figure is at variance with the estimates shown in figure 4, as made by county agents, millers, and farmers. The average individual still believes that "red rust" has little direct bearing on the final wheat yield, so that the estimate of 9.1 percent loss (fig. 4) is rather an admitted concession on their part. The writers' estimate of 12 percent (20 2/3 million bushels) loss for Kansas is believed to be conservative; in fact, some observers have felt that even this figure is too low. The losses were very light and often negligible in the extreme western part of the State and were heaviest in the south-central counties, which normally produce the bulk of the Kansas wheat crop.

Not only was the 1938 leaf-rust epidemic extremely heavy, but it was also notable in that certain varieties of wheat, known to have a certain amount of field resistance, were heavily infected before the end of the season. Kawvale, which had shown promising resistance in 1935 and 1937, was rather heavily infected before harvest, although it exhibited considerable resistance earlier in the season. Iobred behaved in a similar manner, a fact probably attributable to the presence of many physiologic races of the fungus. Analyses of Kansas collections again indicated race 9 as the most abundant and widespread race, although races 15 and 37 also were important. Races 5, 13,19,28, and 65 also were found in occasional Kansas collections.

None of the commercial varieties of hard red winter wheat exhibited a marked degree of resistance. Tenmarq and Chiefkan were not so severely rusted in late season as Turkey, Kharkof, Kanred, Blackhull, and Early Blackhull. In the case of Tenmarq this lower amount of infection is known to be due to a certain degree of resistance. In Chiefkan, however, the small amount of leaf rust was due principally to a severe physiologic chlorotic mottling of the leaves that developed before leaf-rust infection became heavy.

It is impossible to estimate how much the heavy leaf-rust infection had to do with the deterioration of the Kansas wheat crop during the late part of the 1938 season. The writers observed that where deterioration was most rapid, severe leaf-rust infection was extremely heavy earlier in the season. It is believed that heavy leaf-rust infection, combined with too much moisture during May, was largely responsible for much of the lodging and premature death of the plants in mid-June, but so far no method has been devised to prove that point.